FLIGHT CRITICAL SYSTEMS AND INFORMATION INTEGRITY (FCSII) SUBTEAM INVESTMENT AREAS

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1.0 Flight Critical Systems and Information Integrity Charter

Justified by the accident/incident data, the charter of the Aviation Safety Investment Strategy Team (ASIST) Flight Critical Systems and Information Integrity (FCSII) Subteam was to identify potential investment areas in flight critical systems and information integrity research, technologies, and development that would address specific and critical aviation safety needs for any/all classes of air vehicles (needs common to all classes are highly desirable). Vehicle classes specifically addressed are transports, rotorcraft, and general aviation (GA). Flight critical systems are those necessary for the safe flight of an aircraft and that have a probability of failure of ten to the minus nine. Information integrity covers technologies that enable and assure the safe and secure transmission of information, voice and digital, both within the aircraft and to/from the outside environment. Technologies addressed cover the entire life cycle of aircraft and systems, focusing on all technologies and approaches that contribute to safe flight. The phases include design, verification, validation, certification, operation, maintenance, and aging. Two kinds of aircraft systems were addressed: safer "existing" flight critical systems and systems specifically added for safety reasons (e.g. monitoring, alternate control).

In the current aviation system, flight critical systems and information integrity are not the leading causes of accidents. Nevertheless, the FCSII Subteam assumed that there are accidents that have occurred where the onboard systems played a contributing factor, one of accident precursor. It was also assumed that in the future, as more digital onboard systems become flight critical and the overall aircraft becomes more integrated in terms of functionality, then there will be increased potential for these systems to present greater safety risks.

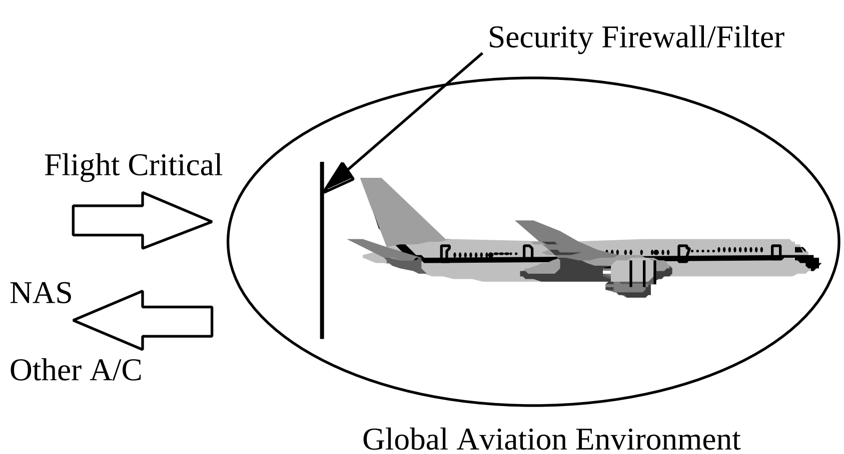

Figure 1. Scope of FCSII charter

2.0 Current and Future FCSII Needs

Current Needs Assessment	Solution/Intervention Areas							
Issues	Sensing	On-board Algorithms (e.g. control, health monitoring)	Actuating (incl. Hydraulics and Electric)	Maintenance & Inspection	Materials & Structures	Interface, Comm., & Display	Design, Verification, Certification, Manufacture	CNS/ATM
Airframe	2	1	1	1	2	3	1	
Propulsion	2	1	2	1	1	2	1	
Systems	2	1	1	1	3	2	1	2
Integration	2	1	3	2	3	1	1	2
Information Integrity	2	2	3			1	1	1
Air Traffic Control						1	1	1

1	High Need
2	Medium Need
3	Low or No Need
	Not Applicable

Figure 2. Current FCSII Needs--Transports

Current Needs Assessment	Solution/Intervention Areas							
Issues	Sensing	On-board Algorithms (e.g. control, health monitoring)	Actuating (incl. Hydraulics and Electric)	Maintenance & Inspection	Materials & Structures	Interface, Comm., & Display	Design, Verification, Certification, Manufacture	CNS/ATM
Airframe	2	1		1	2		1	
Propulsion	2	1	1	1	2	1	1	
Systems	2	1	1	1		1	1	1
Integration	2	1	2	2		1	1	1
Information Integrity	2	2	2				1	1
Air Traffic Control						2	1	1

1	High Need
2	Medium Need
3	Low or No Need
	Not Applicable

Figure 3. Current FCSII Needs--Rotorcraft

Future Needs Assessment	Solution/Intervention Areas							
Issues	Sensing	On-board Algorithms (e.g. control, health monitoring)	Actuating (incl. Hydraulics and Electric)	Maintenance & Inspection	Materials & Structures	Interface, Comm., & Display	Design, Verification, Certification, Manufacture	CNS/ATM
Airframe	2	1	1	1	1	3	1	
Propulsion	1	1	1	1	1	3	1	
Systems	1	1	2	1	2	2	1	2
Integration	2	1	3	1	3	1	2	2
Information Integrity	1	1	1			1	1	1
Air Traffic Control						1	1	1

1	High Need
2	Medium Need
3	Low or No Need
	Not Applicable

Figure 4. Future FCSII Needs--Transports

Future Needs Assessment	Solution/Intervention Areas							
Issues	Sensing	On-board Algorithms (e.g. control, health monitoring)	Actuating (incl. Hydraulics and Electric)	Maintenance & Inspection	Materials & Structures	Interface, Comm., & Display	Design, Verification, Certification, Manufacture	CNS/ATM
Airframe	2	1		1		3	1	
Propulsion	1	1		1		2	1	
Systems	1	1		1		2	1	2
Integration	2	1		2		1	2	2
Information Integrity	1	1				1	1	1
Air Traffic Control						1	1	1

1	High Need
2	Medium Need
3	Low or No Need
	Not Applicable

Figure 5. Future FCSII Needs--Rotorcraft

3.0 Relevant Existing NASA and FAA Programs

Area	Level II Program	Level I Program	Goal	Funding
Integrated Systems Errors	Error-Tolerant Air-Ground Integration Research	Aviation Operations Systems	Develop mutual and integrative design methods of both aircraft subsystems and operator procedures	$6.5M/5 yrs.
Airframe Systems	Aging Aircraft	Advanced Subsonic Technologies	Accurate prediction methodologies & quantitative reliable NDE for thin metallic fuselage components in aging aircraft	$6.6M/3 yrs.
Airframe Systems	Aircraft Life Extension	Airframe Systems	Accurate prediction methodologies & quantitative reliable NDE for thick metallic components, such as wings, in aging aircraft	$9M/5 yrs.
Propulsion	Propulsion	Advanced Subsonic Technologies	Characterize aeroelastics for turbomachinery, lifting mathodology for primary engine composite structures and reliability of disk and blade materials	$19.3M/5 yrs.
Propulsion	Civil Tilt Rotor (CTR)	Advanced Subsonic Technologies	Demo engine system concepts for One Engine Inoperable contingency power for CTR	$8.3M/4 yrs
Propulsion	HiTemp	Propulsion Systems	Develop lifting & durability models, NDE techniques, and strain measurement techniquies for metallic, ceramic, and polymer materials in critical system components	$39M/6 yrs.
Propulsion	Physics Process Modeling	Propulsion Systems	Develop inherently more reliable critical components for small gas turbine engines	$5M/5 yrs.
Propulsion	Smart Green Engine	Propulsion Systems	Develop technologies for compression system stalilization and turbomachinery durability	$9.7M/6 yrs.
Propulsion	Tools	Propulsion Systems	Develop interdisciplinary tools that focus on improving prediction of compressor stall margin	$3M/3 yrs.
Propulsion	SAFOR (transmission	Rotorcraft	Develop technologies for ultra-safe & highly reliable transmissions & drive systems	$0.25M/6 yrs.
Avionics	Error-Proof Flight Deck	Airframe Systems	Develop technologies to protect against adverse consequences assoc. with errors in the flight deck and critical systems	$7M/5 yrs.
Avionics	Total Aircraft Management Environment	Airframe Systems	Develop technologies for integrated adaptive control of airframe systems that execute pilot intent without error	$5.2M/5 yrs.
Avionics	Intelligent System Controls and	Information Technology	Demo formal design and verification methods on industrial applications	$0.5M/1 yr.
ATM Systems	Methods for Analysis of System Stability and Safety	Aviation Operations Systems	Planned new Start in FY 1998	$14M/5 yrs.
ATM Systems	Error-Tolerant Air-Ground Integration Research	Aviation Operations Systems	*Same as first row*	

Figure 6. NASA Level II R&T Base Programs

RPD	RPD Name	Project Name	RPD Goal Section, Outcome	Key Words
RPD 161	Structural Integrity of Commuters	Aging Aircraft	Reduce likelihood of fatalities & injuries resulting from fatigue failures of small transport & commuter a/c structures	Damage tolerance methods, analyisis & design; Software tools RAPID & NASGRO
RPD 519	Rotorcraft Structural Integrity and Safety Issues	Aging Aircraft		
RPD 511	Manitenance & Repair	Aging Aircraft	Improved maint. & repair policies & procedures that will reduce mainit., repair, & inspection related accidents by 10%	Metallic structures; composites; NDI for turbine engines
RPD 556	Continued Airworthiness of Aircraft Engines	Aging Aircraft	Reduce # of deaths that result from a/c engine failures	Inspection and maint. for non-rotating components; fatigue crack growth in propellers; ultrasonic inspection; eddy current inspection
RPD 515	Structural Response Simulation & Modeling	Aging Aircraft	Avoid accident in large transport a/cdue to Widespread Fatigue Damage (WFD) for all a/c operating until 2004	Full-scale panel testing; FEM; crack-growth prediction; Residual strength analysis
RPD 562	Inspection Systems Research & Development	Aging Aircraft	By year 2004, reduce by 10% a/c accidents & incidents due to inspection preventable failures	Widespread Fatigue Damage; inspection systems
RPD 419	Turbine Engine Research	Propulsion & Fuel Systems	Reduction in annual # of airline passenger injuries & fatalities, a/c damage, & lost revenue by reducing intrinsic turbine engine rotor uncontained failure rate	Titanium alloy high energy rotating components; design, manufacturing, & inspection
RPD 504	Advanced Materials/Structures	Advanced Materials/ Structures	Structural safety of aircraft components constructed of adv. materials	Composite materials & structures; data base; standard test methods; certification basis; GA/AGATE
RPD 516	Aircraft Catastrophic Failure Prevention Program	Aircraft Catastrophic Failure Prevention Program	Mitigate hazards of uncontained engine rotor disk failures, increase survivability of a/c w/extensive failures/malfunctios/damage of flt ctrl system	Uncontainment mitigation tools; a/c vulnerability assessment tool kit; materials & technologies to mitigate uncontainment; Intelligent Damage Adaptive Control System; Crew response to propulsion problem; engine imbalance loads model
RPD 559	Electromagnetic Test and Analysis	Flight Safety/Atmospheric Hazards		
RPD 560	Flight Controls & Digital Avionics Systems	Flight Safety/Atmospheric Hazards		

Figure 7. FAA Research Program Descriptions (RPD's)

4.0 Recommended FCSII Investment Areas

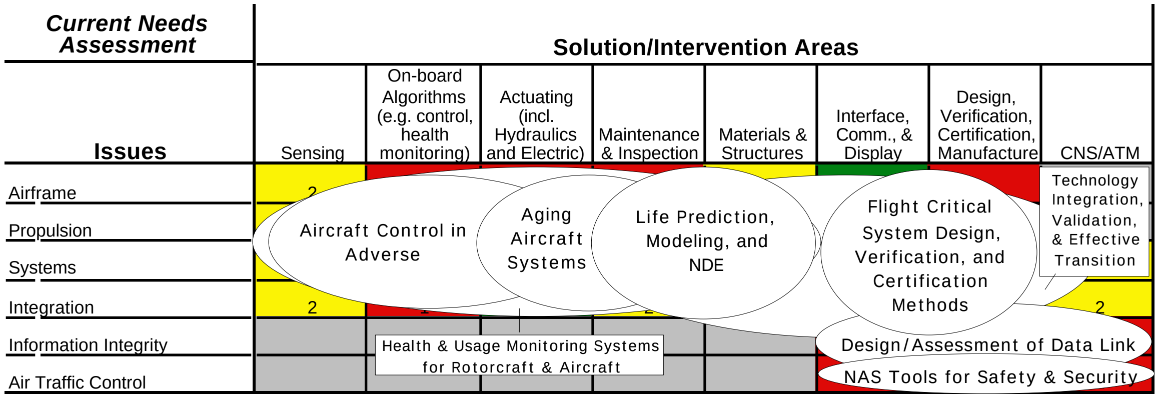

Figure 8. Current (5-year) FCSII Investments

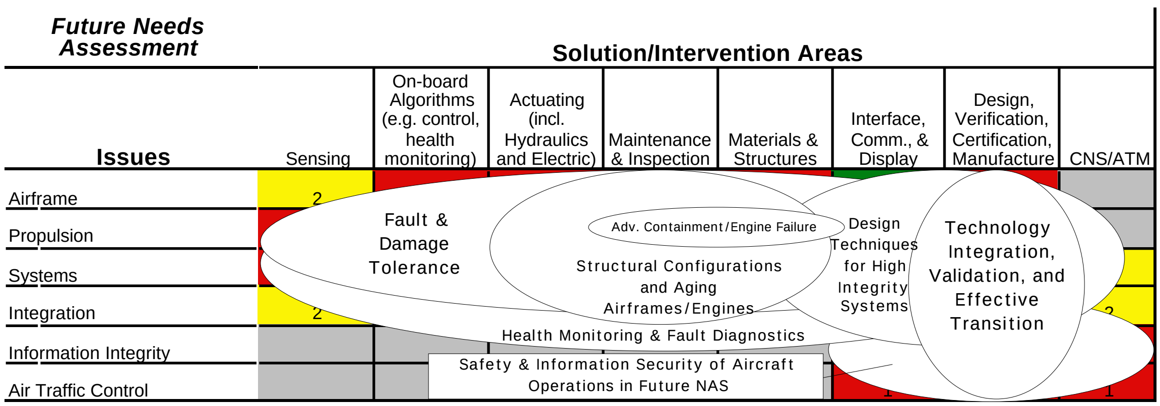

Figure 9. Future (15-years) FCSII Investments

4.1 "Current" (5-Year) Investment Areas (Ovals)

4.1.1 Aircraft Control in Adverse Conditions

Goals and Objectives

Develop system technologies to prevent accidents due to unexpected failures or damage that may affect aircraft control, stability, and safety. Situations of concern include system and instrumentation failures, lightning and high-intensity radiated fields (HIRF) upsets (including inadvertent and deliberate human-induced HIRF), and physical damage due to foreign objects (FOD) and malicious (terrorist) threats.

Approach

- Alternate control systems would be developed for prevention and recovery of incidents and accident precursors and prevention of accidents.
- Develop data bases from analytical, simulation, and flight investigations on how systems/aircraft function and perform in failure/damage situations and on which to base

system modifications and new designs. These data bases also become key inputs to new training procedures and tools.
- Develop and demonstrate in the lab and in flight, enabling, alternate emergency backup systems allowing an aircraft to become more "damage tolerant" or "fault transparent".
- Identify, develop, compare, and validate fault identification, system reconfiguration (both hardware and software) techniques
- Develop and demonstrate maturity of algorithms for real-time system identification and on-line control effector management/optimization

Potential Investments

Primary Investments (as ordered by FCSII Subteam):

1. Awareness of the state of the aircraft and all systems at all times
2. Control of aircraft in upset and dramatic failure situations
3. Adaptive control or intelligent adaptive control
4. Propulsion system malfunction plus inappropriate crew response
5. Performance monitoring in take-off and landing
   - Full-time performance margin indications
   - Auto go-around

Other potential Investments:

- Detection of failed instrumentation
- Recovery from unusual attitudes
- Analysis of hazards, risks, and threats to aircraft
- Improved control laws--robust, adaptive (all vehicle types)
- Data bases on aircraft response to adverse conditions (CFD, wind tunnel testing, flight testing)
- Integrity of backup systems
  - Level of integrity
  - Functionality of backup
- Control techniques reducing adverse effects on aircraft during landing
- Better information on the state of the landing gear
- Handling in adverse, turbulent conditions (e.g. clear air turbulence)
- Wireless control system technology
- More-electric aircraft systems (i.e. control, brakes)
- SOS buttons
- Standardize on one approach to collision avoidance
- Digital data coupled with GPS
- Vertical position with respect to terrain using GPS
- Real-time human and aircraft performance monitoring systems
- Care-free flying (envelope protection)--included stall and spin protection
- Predictive/instantaneous flight control correction (e.g. laser radar)
- Smart structures
- Active control and reconfiguration
- Electronic primary flight displays for general aviation aircraft
- Decoupled flight control for GA aircraft
- Airborne power line avoidance system effectiveness for Rotorcraft

4.1.2 Life Prediction, Modeling, and NDE

Goals and Objectives

Develop technologies to extend the life of airframe and engine materials and structures and assure safe operation.

Approach
- Investigate processes of cracking, corrosion, wide-spread fatigue damage, and residual strength.
- Develop analytical modeling and prediction techniques to assess structural integrity
- Develop advanced high-resolution non-destructive evaluation (NDE) and inspection (NDI) techniques

Potential Investments
- Advanced high-resolution non-destructive evaluation for airframe and propulsion systems (all vehicle types)
  - Detection of smaller cracks
  - Detection of cracks deeper into the test specimen
  - Structures and propulsion systems
- Investigation onset and effects of wide-spread fatigue damage
- Data mining and correlation for diagnostics and maintenance
- Corrosion/fatigue prediction methodology
- Dynamic fatigue resistant structure
- Corrosion/fatigue structural demonstration. Develop methods for analyzing the structural integrity of corroded aircraft structure.

4.1.3 Aging Aircraft Systems

Goals and Objectives
Develop concepts and techniques for assessing and extending the useful safe life of all aircraft systems, including hydraulics, wiring, and electro-mechanical systems.

Approach
Investigate the deteriorating effects of age on non-structural components, including electrical wiring, connectors, wiring harnesses, and cables; fuel, hydraulic and pneumatic lines; and emergency oxygen lines. Investigate the deteriorating effects of age on critical components of electro-mechanical systems, such as pumps, sensors, and actuators. Develop actions needed to preclude catastrophic failure of aircraft due to the failure of these components.

Potential Investments
- Data mining and correlation for diagnostics and maintenance
- Parts pedigree concepts (e.g. self-identification of approved parts)
- Extended tire life
- Concepts and life extension of lightweight landing gear
- Oil bath lubrication of wheel bearings

4.1.4 Flight Critical System Design, Verification, and Certification Methods

Goals and Objectives
Develop design, verification, and validation methods and techniques for aircraft systems that are flight critical and proposed new safety technologies

Approach
This investment will develop techniques that will enable evaluation and demonstration of required levels of reliability, availability, integrity, and safety for flight critical systems. Investigation will include new ways to increase the fidelity and decrease the time required for design, verification, and certification of new flight systems that have impact on aircraft safety or will be used to prevent or recover from accidents. As greater reliance is shifted to

electronic systems for critical functions, the need for new approaches to be considered under this investment area will increase in importance. A key is to make systems more “certifiable”, not to certify new products or replace the FAA type certification process. This investment would help accelerate the lessons learned on new technologies by focused research on key design criteria. Human/automation interaction considerations and human-centered design methodologies will be integrated throughout. System architectures and data fusion issues for integrated systems concepts would be investigated. Techniques will be investigated to assure information integrity and security of flight system operation in light of malicious threats (e.g. terrorism) and environmental threats (e.g. HIRF, lightning). Specific system concepts would be used to explore methods to verify that a given approach to solving a major safety problem will function as intended and not result in new kinds of failures and future accidents. An example of this might be the Verification and Certification of new CFIT technologies. It is also anticipated that this investment area would provide a technology foundation that would enable further development needed to achieve future goals and objectives (15 years and beyond) and deal with possible future emerging issues and concerns such as radiation (cosmic particle) environment and Commercial-Off-The-Shelf (COTS) hardware and software.

<u>Potential Investments</u>
Primary Investments Areas (as ordered by FCSII Subteam):
1. Analytical investigations of systems that are flight critical/essential
2. Pilot-vehicle interactions, including Aircraft-Pilot Coupling (APC) and Pilot Induced Oscillations (PIO)
3. Software certification--proof of operation vs. validation
4. Robust partitioning to maintain separation between functions in integrated systems
5. Modeling affects of technology insertion

Other Potential Investments:
- Modeling of systems
- Integration of tools used in various phases of development
- Enabling certification “credit” for tools
- Simulation technologies (emulation, modeling at lower levels)
- Improved control law design approaches for aircraft and rotorcraft
- Product-based/analytical software development standards
- Certification techniques for “imprecise” (non-deterministic) systems
- Information integrity of onboard systems
- Functional hazard analysis
- Physical upset assessment methods (i.e. lightning, electromagnetic environments)
- System nuisance trip avoidance criteria
- Degree of auto-recovery/take-over authority
- Auto-pilot integration design constraints
- Certification/validation issues associated with digital terrain systems
- Dissimilar system flight demonstrations and comparisons to validate/certify other system concepts (e.g. On-line terrain measurement to validate a CFIT system implementation, etc.)

4.1.5 Technology Integration, Validation, and Effective Transition

<u>Goals and Objectives</u>
Develop methods and tools to improve the integration of enabling safety technologies into existing and new aircraft and validate the effectiveness of the overall impact on aircraft operations and safety.

Approach

This investment area will help focus the integration and validation aspects of safety research and technologies. The ultimate result of all investment is affected by the integration of systems and human operations on the aircraft. This becomes a flight critical issue when a component, sub-system, or system failure on the aircraft contributes to a chain of events leading to a fatal accident that is ultimately categorized as "the pilot did not follow correct procedure". Enabling technologies in the areas of information technologies, human factors research, weather-related research, and flight critical systems will continue to be developed. It will explore rapid, low cost methods to integrate ground-based, safety research with the flight environment.

This area of investment will also explore alternative methods of establishing a low cost approach to retrofitting current GA, Rotorcraft and transport aircraft designs with existing or new safety related technologies. The area of investment has two intersecting approaches that result in the ultimate goal of increasing safety and reducing accidents in the "increasing" fleet of "existing" vehicles. One approach will examine existing GA, Rotorcraft and transport aircraft designs and system architectures for areas of potential, low cost retrofit of new technology. The other intersecting approach will be to develop the enabling technologies for those identified vehicle designs that would improve safety. The enabling technologies may be low cost approaches, smaller size hardware, innovative installation techniques, etc.

This area of investment would examine the low cost approach of enabling older fleet vehicles to take advantage of new technologies. Also address the questions such as "what will the introduction of technology do to the overall system reliability". Weight consideration will also be addressed

Potential Investments

- Retrofitability:
  - New ideas for incorporating "new" technology, components, and systems into existing aircraft
  - Effective transition of enhanced technology
  - Identification of "multi- use" capabilities with existing components and subsystems.
  - Software modifications that can be partitioned in such a manner as to not require expensive aircraft re-certification procedures, but would enable the implementation of a safety function.
  - Incorporation of an airframe-wide health monitoring system by using advanced sensor technologies that are not incorporated "into" the structure, but "on to" the structure to sense micro-cracks, leaks, or some other system problem.
- Safety Testbed(s) with rapid, low cost reconfiguration capabilities. The reconfiguration concepts would include items such as:
  - Reconfigurable cockpits for early and frequent low cost flight validation of research concepts being explored in ground-based systems
  - Reconfigurable control systems for demonstration of alternate control concepts in emergency situations
  - Reconfigurable data systems for fully integrated evaluations of data fusion concepts
- Safety Testbed(s) would be used to improve and verify the approach to aircraft systems design which have significant human-aircraft systems interaction implications, such as:
  - Aircraft-pilot coupling issues
  - Validation of techniques/systems to aid in recovery from unusual attitudes
  - Pilot associate concepts for emergency (i.e. high risk) situations
  - Error-free requirements and design for entire system (not just cockpit)
  - Developing extremely low cost night navigation aids (e.g. FLIR's)
  - UV frequency detection for runway lights pilot display through adverse weather

- Commercial pilot demonstrations, validation of human-machine interfaces

4.1.6 Design and Safety/Risk Assessment of Data Link Technologies

Goals and Objectives
Identify and assess safety risks and vulnerabilities associated with data (could include voice) communication to digital communication between air and ground and within the aircraft, with emphasis on information integrity and the human-machine interface. Identify critical safety issues, and strategies for addressing them. Investigate safe, efficient data link concepts for off-board Air Traffic Management (ATM), Weather, Terrain data to onboard systems.

Approach
Address four areas: authenticity, integrity, availability, and system bandwidth. Potential starting points include secure data links used by DoD and those used employed for Space Shuttle operations.

Potential Investments
- Ground systems
- Onboard systems
- Communications, navigation, and surveillance (CNS) technologies
- Increased bandwidth

4.1.7 NAS Tools for Safety and Security

Goals and Objectives
Develop tools and techniques to analyze the survivability of the National Airspace System (NAS) against threats of varying levels of strength and to identify where safeguards must be implemented.

Approach
As the National Airspace System (NAS) evolves toward the concept of "Free-Flight", more decision making will be performed by air crews and by airline operations centers, rather than solely by ground-based air traffic control (ATC). This shift will cause a large increase in the amount of information on which those decisions are made, much of it to be exchanged in digital form. The growing volume of digitally transmitted data is a special security concern, because it is easier to forge and harder to authenticate its source. Since the entire Free-Flight concept is so new, the effects (positive or negative) of proposed security measures are difficult to assess. The need exists to validate security measures by testing them within a simulated Free-Flight environment.

NAS is undergoing a rapid and far-reaching modernization, which will include, to the greatest extent feasible, the use of Commercial-Off-The-Shelf (COTS) information technology products, including products for information security. Technology changes in the computer industry approximately every 18 months while the certification process takes a minimum of 36 months. While the essential features of such products can be determined from vendor presentations and established standards, their overall quality remains difficult to assess and expensive to test. Existing federal government evaluation programs provide only limited information, and are often quite old relative to the product's life cycle. Moreover, each potential security product requires detailed analysis of its features to assess its applicability in the NAS. The need exists for a capability wherein potential COTS security technologies can be subjected to comparative security testing and evaluation towards certification for use in the NAS, so that products selected for use in the NAS will be of both the greatest overall quality and the most appropriate specific features.

Accountability over Data Link requires personal identification and authentication (I&A) both on the part of controllers and pilots using the NAS. The methodology of manual log-in and reusable passwords is obsolete technology of questionable value. Air traffic personnel have objected to manual log-in and password authentication for operational reasons, and similarly pilots will resist manual log-ins. A modern alternative I&A methodology employs technology that requires little or no overt action on the part of the individual, which appears attractive and more acceptable to users. The use of smart cards encapsulating active chips and optical recognition are in common use today. Some high security environments have used active chips in badges that are sensed without any action on the part of the wearer.

A more robust air/ground Data Link is needed that will service the entire aviation community, commercial and general aviation alike, with capabilities that will provide adequate coverage for oceanic/remote areas and domestic flights. The current system is lacking in three areas: bandwidth, costs, and security features. This task area would investigate the application of current and future communications technology toward providing a relatively high bandwidth, low cost, robust A/G data communications system with adequate security features to support the more sophisticated aircraft systems of the Free Flight era.

<u>Potential Investments</u>

- Simulation tools to baseline NAS and flight systems security, with and without security technologies added
- Tools to perform security technology evaluation
- Tools for automated identification and authentication of system users, controllers or pilots.
- Design and implement robust, secure air/ground data link

4.1.8 Health and Usage Monitoring Systems for Rotorcraft and Aircraft

<u>Goals and Objectives</u>

Validate improved techniques for vehicle health and usage monitoring to prevent catastrophic failure and decrease maintenance costs.

<u>Approach</u>

As much as 4-to-1 reduction in maintenance cost has been implemented within DoD in this area. This investment area would demonstrate/transition this concept to the commercial transportation world. New enabling technologies would be explored to demonstrate applications for all classes of vehicles, including space transportation. Health monitoring information would aid the pilot in real-time decision making for catastrophic avoidance. Trends within tolerances would be identified and an integrated ground and air environment application would be demonstrated.

<u>Potential Investments</u>

A comprehensive structural and systems health monitoring system that provides integrated, automated, and near real time assessment of structural integrity for both metallic and composite structures and systems health

4.2 "Future" (15-Year) Investment Areas (Ovals)

4.2.1 Design Techniques for High-Integrity Complex Digital Systems

Goals and Objectives
Develop design methods for future highly integrated flight critical systems.

Approach
Investigate integrated design, verification, and validation methods for new system concepts that exploit future "smart" technologies and digital systems design. It is envisioned that onboard systems will be highly integrated, with the potential for physical and analytical redundancy. The complexity of onboard systems is also expected to increase with the advent of free flight.

Potential Investments
- Simulation (emulation, modeling at lower levels)
- Hardware considerations--compatibility, upgrade, retrofit
- Modeling of systems
- Modeling affects of technology insertion
- Multiple techniques in a coordinated way
- Analytical investigation
- Systems that have flight critical and essential systems.
- Highly integrated systems.
- Improved multi-axis control designs for rotorcraft
- Software certification--proof of operation vs. validation
- Electronic primary flight displays for GA
- Product-based/analytical software development standards
- Certification techniques for "imprecise" systems
    - Non-deterministic systems (advisory in nature)
- Functional hazard analysis
- Robust partitioning to maintain separation between functions in integrated systems

4.2.2 Structural Configurations and Aging Airframes/Engines

Goals and Objectives
Develop future "aging aircraft" technologies, including composite materials and structures as well as metallic.

Approach
This includes the airframe, engine, and systems.

Potential Investments
- Composites structural configurations and aging
- Long term durability components for engines and airframes
- Investigation of new materials for aircraft
- Investigation of materials candidate for retrofitting on existing fleet
- Fracture-resistant engine casting alloys for rotorcraft
- Pedigree parts concepts:
    - Unapproved parts that don't meet specifications
    - Bar coding, signatures, embedded magnetic signatures

4.2.3 Fault and Damage Tolerance

Goals and Objectives
Develop concepts and technologies for tactical, real-time aircraft control and management in failure, damage, and upset situations.

Approach
Investigate and develop a combination of technologies that enable safe flight in presence of failure and/or damage. This includes essentially all technology disciplines and all phases of product/aircraft life cycle, from design to maintenance.

Potential Investments
- Redundancy--physical and analytical
- Reconfigurable control
- Embedded backup control devices and secondary control systems
- Neural networks that identify critical aircraft stability parameters.
- On-line learning neural networks that can adapt to changing conditions such as damage to the vehicle.
- Fault detection, identification, and reconfiguration
- Electromechanical actuators
  - Aspects of more-electric aircraft.
  - Electricity more flexible than hydraulics when it comes to reconfiguration
  - Reduce fire hazard associated with hydraulics
- Dissimilar redundancy and data corroboration--hardware and software
- Aircraft control demonstration of similar feedbacks from multiple sources (i.e. air data from engine, etc.)
- Damage caused by environment and malicious threats
- Foreign Object Damage (FOD)
- Integrated propulsion controls with redundant reconfigurable modes
- Vehicle stabilization Systems for Rotorcraft
- Damage-tolerant rotor lifting
- Bird ingestion in small turbine engines
- Improved protection from High Intensity Radiated Fields (HIRF) and Lightning
- Care-free flying (envelope protection)
- Active control and reconfiguration
- Smart structures
- Structural damage and self healing

4.2.4 Health Monitoring and Diagnostic Systems

Goals and Objectives
Investigate the integration and validation of existing and future sensing/processing technologies to better aid in system-wide and airframe-wide health monitoring. Distributed, smart systems concepts and onboard diagnostic system architectures would be explored. Post flight comparisons of information from existing “manual, human-based” systems to “new experimental systems” would be accomplished to validate new concepts. Aging aircraft and aging systems (propulsion and avionics) will require real-time trend analysis to prevent the failure which could lead to an accident. The economic factor here is improved maintenance procedures by use of better airframe and system information to the appropriate personnel. “Just-in-time” information concepts to prevent delays and avoid costly inspection down times. Various systems architectures would be explored to develop optimum implementation and retrofit options.

Approach
• General concepts:
  - Aircraft health monitoring
  - Engine health monitoring by emissions & debris
  - Intelligent engines
  - Electronic checklists
  - Pilot's associate
  - Exhaust-plume spectroscopy methods for rotorcraft
  - On-board monitoring of load cycles
  - Engine controllers that "tell" pilot when failed
  - Alleviate false indication of faults
  - Eliminate maintenance induced failures
  - Better information on the state of the landing gear

Potential Investments
• Diagnostics--real-time, full-time (Tactical)
  - Onboard diagnostic system architectures
  - Advanced diagnostics technology (e.g. intelligent load monitoring)
  - Awareness of the sate of the aircraft and all systems at all times
  - Information in dramatic failure situation
  - Detection of failed instrumentation
  - Smart actuators with integrated diagnostics
  - Leak Isolation and Diagnostics
  - Real-time human and performance monitoring systems
  - Distributed flight data sensing and recording (MEMS)
• Health monitoring - periodic, resulting from health monitoring (Strategic)
  - Intelligent monitoring
  - Comprehensive engine health monitoring system
  - Health & Usage Monitoring Systems (HUMS)
  - Data about systems
  - Trend analysis
  - Sensing of pilot intent

4.2.5 Advanced Containment Concepts for Engine Failure

Goals and Objectives
Develop enhanced, lightweight containment systems. Investigate long-life durability of materials and components to double engine "time on wing" and reduce disassembly costs and associated human errors.

Approach
• Containment concepts and technologies
• Inspection techniques for rotating components
• Physics of disc burst
• Mitigation of aircraft damage due to uncontained engine failure
• Longer life bearings, mechanical components, propellers, & rotor blades

Potential Investments
• Durable designs/design optimization
• Reduced blade flutter/forced vibration
• Design/attachments for unexpected imbalances
• High quality Ti & Ni melt stock
• Low crack growth Ti & Ni alloys
• Structural damage under high rate loading

- Surface enhancement treatments to increase life
- Fracture-resistant case, blade, and disk alloys/designs
- Light weight containment systems
- Long-life durability materials and components to double engine “time on wing”
- High-resolution NDE of disks, blades, and casings

4.2.6 Technology Integration, Validation, and Effective Transition

This area is the same as the one described in Section 4.1.5. It was felt that the integration and validation of technology is an area to be pursued throughout the program, which is why it is represented in the 5 and 15-year time frames.

4.2.7 Safety and Information Security of Aircraft Operation in Future National Airspace System

Goals and Objectives
Develop enabling technologies to assure safety and information security.

Approach
Working closely with the AATT program, define concepts and technologies for safe and secure operations of aircraft in the future airspace system. Areas investigated will be ones that are clearly not covered in AATT.

Potential Investments
- Fail/operational, fail/safe ATM
- Design of systems to operate safely and securely in future NAS.
- Secure data link is fundamental for CNS/ATM.
- Impact to safety and security on aircraft operating in the future NAS.
- Full 4D navigation with coordination of ATC and other traffic
- Standardize on one approach to collision avoidance
- Digital data coupled with GPS
- Vertical position with respect to terrain using GPS
- GPS Wide-Area Augmentation System (WAAS)
- Controller identification and authentication

5.0 FCSII Investment Area Prioritization, Funding, and Workforce

FCSII Investment Areas	Priority	Preliminary Funding Profile ($M) 1998	1999	2000	2001	2002	Total FCSII Funding (5 years)
Aircraft Control in Adverse Conditions	1	4	5	7	7	7	30
Advanced Containment Concepts for Engine Failure	2	4	5	5	5	6	25
Technology Integration, Validation, & Effective Transition	3	6	6	6	6	6	30
Life Prediction, Modeling, & NDE	4	6	6	6	6	6	30
Flight Critical System Design, Verification, & Certification Methods	5	5	5	5	5	5	25
Design & Safety/Risk Assessment of Data Link Technologies	6		2	3	3	4	12
NAS Tools for Safety & Security	7	1	2	3	3	3	12
Health & Usage Monitoring Systems for Rotorcraft & Aircraft	8	1	1	2	1	1	6
Aging Aircraft Systems	9	1	1	2	1	1	6
Fault & Damage Tolerance	10	1	2	3	3	3	12
Health Monitoring & Fault Diagnostics	11	2	2	2	3	3	12
Design Techniques for High-Integrity Complex Digital Systems	12		1	2	4	5	12
Structural Configurations and Aging Airframes/Engines	13			1	2	3	6
Safety & information security of flight operations in future NAS	14		1	1	2	2	6
TOTAL		31	39	48	51	55	224

Figure 10. Prioritized FCSII Investments & Funding Profiles

FCSII Investment Areas	CS FTE's (5 years)	Skill Mix
Aircraft Control in Adverse Conditions	50	Flight Systems, Flight Research, Dynamics & Control, Aerodynamics
Advanced Containment Concepts for Engine Failure	50	Propulsion Systems, Materials & Structures
Technology Integration, Validation, & Effective Transition	50	Flight Research, Flight Systems
Life Prediction, Modeling, & NDE	75	Materials & Structures, Propulsion Systems
Flight Critical System Design, Verification, & Certification Methods	30	Flight Systems, Digital Systems Design, Integrated Aircraft Design, Human Factors
Design & Safety/Risk Assessment of Data Link Technologies	20	Information Technology, Flight Systems, Aviation Operation Systems, Flight Research, Human Factors
NAS Tools for Safety & Security	15	Aviation Operation Systems, Information Technology
Health & Usage Monitoring Systems for Rotorcraft & Aircraft	15	Smart Systems, Flight Systems, Information Technology, Mechanical Engineering, Human Factors
Aging Aircraft Systems	15	Materials & Structures, Mechanical Engineering, Propulsion Systems
Fault & Damage Tolerance	15	Digital Systems Design, Smart Systems, Materials & Structures
Health Monitoring & Fault Diagnostics	15	Smart Systems, Flight Systems, Information Technology, Human Factors
Design Techniques for High-Integrity Complex Digital Systems	15	Flight Systems, Digital Systems Design, Integrated Aircraft Design
Structural Configurations and Aging Airframes/Engines	12	Materials & Structures, Propulsion Systems
Safety & information security of flight operations in future NAS	12	Aviation Operation Systems, Information Technology, Flight Systems, Flight Research
TOTAL	389	

Figure 11. Workforce and Skill Mixes for FCSII Investments